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Contribution from the Bureau of Chemistry, CARL L. ALSBERG, Chief, and the Bureau of Entomology, L. O. HOWARD, Chief.

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EXPERIMENTS ON THE TOXIC ACTION OF CERTAIN GASES ON INSECTS, SEEDS, AND FUNGI.

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INTRODUCTION.

Experiments made at American University by the Bureau of Entomology of the United States Department of Agriculture, in cooperation with the Chemical Warfare Service of the United States War Department, on the action of certain toxic gases upon the body louse (*Pediculus corporis* De G.) indicated that further investigation with other insects might be profitable, especially since very little work had been done with respect to their action on insects,[1] fungi, and seeds. Accordingly a committee [2] was appointed to plan a series of experiments to determine the value of these gases for fumigating purposes.

The gases of war value and the apparatus used at American University were obtained through the courtesy of the Chemical Warfare Service. The collection and rearing of the insects and observa-

[1] Bertrand, Brocq-Rousseau and Dassonville (Compt. rend., **169** (1919): 441, 880, 1059, 1061, 1428) have conducted some experiments with chloropicrin on bedbugs and charancon (weevils); Moore (J. Econ. Entomol., **11** (1918): 357) has done some work with chloropicrin against bean weevil (*Bruchus obtectus* Say.), Angoumois grain moth (*Sitotroga cerealella* Oliv.), Indian meal moth (*Plodia interpunctella* Hbn.), Mediterranean flour moth (*Ephestia kuehniella* Zell.), and confused flour beetle (*Tribolium confusum* Duval), as well as (J. Lab. Clin. Med., **3** (1918): 267) for fumigating clothing for the destruction of the clothes louse (*Pediculus corporis* [*vestimenti*]). Moore and Graham (J. Agr. Research, **12**, No. 9 (1918): 579) tested the action of chloropicrin on potato beetle eggs (*Leptinotarsa decemlineata* Say.).

[2] This committee consisted of R. H. Hutchison and E. A. Back, of the Bureau of Entomology, E. R. Sasscer, of the Federal Horticultural Board, and I. E. Neifert, of the Bureau of Chemistry.

tions upon them were performed by G. L. Garrison. The germination tests were made by W. L. Goss, of the Seed-Testing Laboratory of the Bureau of Plant Industry, and the fungicidal results were determined by J. Monteith, jr., and H. F. Bain, of the Federal Horticultural Board, and C. C. Thomas, of the Bureau of Plant Industry.

EXPERIMENTAL WORK.

GENERAL PROCEDURE.

Nearly 800 fumigations, in which 20,000 insects of about 15 different species were fumigated, were made. The following were fumigated in small glass cylinders, both ends of which were covered by cloth held in place by rubber bands: Ants (*Tetramorium caespitum* Fab., *Monomorium minimum* Buckley, *Monomorium pharaonis* L., *Lasius niger* L., var. *americanus* Emery); bedbugs (*Cimex lectularius* L.); bedbug eggs; potato beetles (*Leptinotarsa decemlineata* Say and *Epitrix cucumeris* Harris); flat grain beetles (*Laemophlaeus minutus* Oliv.); sawtooth grain beetles (*Silvanus surinamensis* L.); grain borers (*Rhizopertha dominica* Fab.); flies (*Phormia regina* Meig., *Calliphora vomitoria* L., *Musca domestica* L., *Stomoxys calcitrans* L., *Chrysomyia macellaria* Fab., and *Lucilia sericata* Meig.); roaches (*Blattella germanica* L.); roach egg pods; flour weevils (*Tribolium ferrugineum* Fab.); and rice weevils (*Calandra oryzae* L.). The following insects were fumigated on their hosts: Aphids (*Myzus persicae* Sulz.); white fly (*Aleyrodes vaporariorum* Westw.); Phyllostachys bamboo mite (*Tarsonemus* sp.); and red spider (*Tetranychus bimaculatus* Harvey).

Checks were kept on all insects, and no results are given for insects whose check showed any dead. The observations were begun when the insects were removed from the fumigatorium, and continued up to the time the percentage of dead became constant for any two successive days. The checks and treated insects were kept under the same conditions until the final observation was made. All of the insects, except ants, aphids, red spiders, and white flies, were held in the container in which they were fumigated. The bedbug eggs were fumigated and kept in chiffon-covered pill boxes, in which the eggs had been deposited. After fumigation the ants were removed to tumblers containing moist sand. Having been fumigated on their hosts, aphids, red spiders, and white flies were transferred to glass tumblers containing moist sand and fresh uninfested material. Roach egg pods were handled in the same manner as ants.

The following fungi were treated: Fusarium, Ascochyta, Penicillium, Colletotrichum, and Sclerotium. In some cases these fungi were placed on a petri dish in a drop; in others, sterilized seeds were inoculated by a spore suspension, and exposed in the same manner as the insects.

The apparatus used to maintain concentration and humidity consisted of a gas flow meter and a gas-air flow meter, both calibrated so that the exact amount of gas and gas air flowing at any one time was known, and could be maintained throughout the experiment. The flow of gas-air mixture was kept at approximately normal atmospheric pressure by having the inflowing air withdrawn as fast as it entered. The blast and suction were kept constant by pressure and suction regulators in the form of heads of water through which the excess air was allowed to bubble. The gases of fairly high vapor pressure (those whose pressure was sufficiently great to force them through the gas flow meter) were kept in small steel cylinders.

In order to follow the air through the apparatus and to make more clear the production of a given concentration of a definite humidity, it will be necessary to trace the air from the blast cock through the apparatus. First, the air was passed over the pressure regulator, then into three bottles of sulphuric acid solution having a density which would produce the humidity desired. From there it was forced through glass wool to take up any acid spray; thence to the mixing chamber, where it was joined by the gas. The mixture passed through a calibrated flow meter and into the fumigation jar, which was connected with the suction line that drew off the air and caused the concentration to rise to the desired strength of gas air; that is, the suction line took care of all of the excess gas air.

The valve on the gas cylinder being open, the gas pressure was kept constant by a head of liquid, and the gas was forced through a calibrated flow meter into the mixing chamber. As the humidity of the blast varied from day to day, an arbitrary humidity (40 per cent relative, which is common in Washington) was adopted.

In most of the experiments a 5-liter jar constituted the fumigation chamber. Inasmuch as the rate of flow of gas air was about two liters per minute, and the minimum exposure was seven minutes, ample time was allowed for the change from air to gas air of the proper concentration.

In the case of chloropicrin (which has a low vapor pressure), it was necessary to draw the air through the fumigant for the high concentration. For lower concentrations only part of the air was drawn through and the rest by-passed, and then both reunited as they entered the line to the gas-air flow meters.

The exact concentration of gas was usually determined by absorption in alkaline solution. The details for the concentration determination for each gas are given under the heading of that gas.

The following gases were investigated: Phosgene, cyanogen chlorid, arsine, chloropicrin, illuminating gas, carbon monoxid, and hydrocyanic acid. The last, which is a standard fumigant against many insects, was used for comparison.

PHOSGENE.

Phosgene, or carbonyl chlorid ($COCl_2$), molecular weight 98.92, has a liquid density, at 20° C. under its own pressure, of 1.38. Its boiling point is 8.2° C. The vapor pressure at 20° C. is 1,216 mm. of mercury. It is corrosive to metals and a decolorizer. It is extremely toxic to human beings, and is rather difficult to handle and control.

The concentration of the gas-air mixture was determined by allowing the gas air to pass into a solution of 5 per cent alcoholic sodium hydroxid solution for one minute, then neutralizing with acetic acid and titrating with N/10 silver nitrate. Concentrations of from 0.5 to 4 per cent and exposures for from seven minutes to two hours were tried. The minimum lethal dose of phosgene, with the minimum time to kill, as compared with that of hydrocyanic acid, is given in Table 1.

TABLE 1.— *Relative insecticidal action of phosgene and hydrocyanic acid.*

Insects.	Phosgene (100 per cent lethal).				Hydrocyanic acid (100 per cent lethal).			
	Concentration.	Time of exposure.	Temperature.	Relative humidity.	Concentration.	Time of exposure.	Temperature.	Relative humidity.
	P. ct.	*Min.*	*° C.*		*P. ct.*	*Min.*	*° C.*	
Ants (*Monomorium minimum* Buckley, *Lasius niger* L., var. *americanus* Emery)	0.5	30	19	19				
Ants (*Tetramorium caespitum* Fab.)					0.2	30	25	40
Aphids (*Myzus persicae* Sulz)	1.0	30	31	40	.2	60	24	40
Bedbugs (*Cimex lectularius* L.)	2.0	120	26	40	2.0	30	27	40
Bedbug (*Cimex lectularius* L.) eggs	2.0	120	24	40				
Beetles, Colorado potato (*Leptinotarsa decemlineata* Say)	4.0	120	30	40	.5	15	30	40
Beetle, Colorado potato (*Leptinotarsa decemlineata* Say) larvæ	4.0	120	30	40	.5	15	30	40
Beetles, Flat grain (*Laemophlaeus minutus* Oliv.)	1.0	120	29	40	1.0	60	26	40
Beetles, Potato flea (*Epitrix cucumeris* Harris)	1.0	60	30	40	.5	7	27	40
Beetles, Sawtooth grain (*Silvanus surinamensis* L.)	1.0	120	28	40	1.0	30	28	40
Borers, Grain (*Rhizopertha dominica* Fab.)	2.0	60	29	40	1.0	30	30	40
Flies [1]	[2] .5	7	26	40	[3] .1	[3] 7	25	40
Fly larvæ [4]	[5] 3.0	120	26	40	.1	30	25	40
Fly, White (*Aleyrodes vaporariorum* Westw.)	1.0	30	22	40	[3] .1	[3] 7	30	40
Lice, Body (*Pediculus corporis* Deg.) eggs	[6] 3.0	120	23	40				
Mite, Phyllostachys bamboo (*Tarsonemus* sp.)	1.5	30	25	40	.2	60	24	40
Roaches (*Blattella germanica* L.)	1.5	120	27	40	.2	15	25	40
Roach (*Blattella germanica* L.) egg pods	3.0	120	30	40				
Spiders, Red (*Tetranychus bimaculatus* Harvey)	.5	60	31	40	.2	30	23	40
Weevils, Flour (*Tribolium ferrugineum* Fab.)	[7] 4.0	120	23	40	1.0	30	34	40
Weevils, Rice (*Calandra oryzae* L.)	4.0	120	26	40	4.0	120	28	40

[1] *Musca domestica* L.; *Calliphora vomitoria* L.; *Muscina stabulans* Fall.
[2] Equal to or less than but not more than.
[3] Not minimum lethal treatment.
[4] *Muscina stabulans* Fall.
[5] 90 per cent killed.
[6] 90.6 per cent killed.
[7] 86 per cent killed.

The results in Table 1 show that in every case phosgene is less effective as an insecticide than hydrocyanic acid.

Several varieties of seeds were fumigated with phosgene in the higher concentrations, the results of which are shown in Table 2.

TABLE 2.— *Effect of phosgene on seed germination.*

Kind of seed.	Germination.			
	Check.	Exposed for 30 minutes (temp., 27° C.; relative humidity, 40).		Exposed for 120 minutes (temp., 27° C.; relative humidity, 40).
		2 per cent concentration.	3 per cent concentration.	3 per cent concentration.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Alfalfa, Dakota	81.5	78.5	72.0	82.0
Carrot, Danvers half long	82.5	71.0	69.5	75.0
Clover, Crimson	44.0	42.0	30.5	46.5
Grass, Orchard	42.5	49.0	38.5	46.5
Lettuce, Salamander	86.5	79.0	66.5	70.5
Millet, Turkestan	59.5	61.5	45.5	19.0
Muskmelon, Rocky Ford	63.5	51.0	3.5	0.0
Onion, Australian brown	52.0	54.5	33.0	51.5
Radish, White icicle	95.0	91.5	90.0	93.0
Wheat, Bluestem	48.5	48.0	40.0	20.0

Muskmelon, millet, and wheat were injured the most. The other seeds were not materially affected. In a few cases there seemed to be some stimulation.

Phosgene proved useless as a fungicide against Fusarium, Ascochyta, Penicillium, and Colletotrichum.

Inasmuch as phosgene has no advantage over the fumigants now in use and is less efficient, it is not recommended.

ARSINE.

Arsine, or arseniuretted hydrogen (AsH_3), molecular weight 77.98, has a liquid density, under its own pressure, of 1.36 at 20° C. Its boiling point is −55° C. The vapor pressure is 8,780 mm. of mercury at 10° C.

Arsine is toxic to human beings, and extremely harmful to live plants, in which it produces chlorotic conditions. Metals and glass when in contact with the gas become coated with a fine, mirrorlike deposit of arsenic.

The gas was generated by dropping water on magnesium arsenid and collecting the arsine over saturated sodium chlorid solution. The concentration was determined by absorbing the gas in N/100 iodin solution and titrating with N/100 sodium thiosulphate solution.

Concentrations of from 0.5 to 3 per cent, and exposures of from seven minutes to two hours were used. The minimum lethal dose of arsine for certain periods of time, as compared with that of hydrocyanic acid, is given in Table 3.

TABLE 3.— *Relative insecticidal action of arsine and hydrocyanic acid.*

Insects.	Arsine (100 per cent lethal).				Hydrocyanic acid (100 per cent lethal).			
	Concentration.	Time of exposure.	Temperature.	Relative humidity.	Concentration.	Time of exposure.	Temperature.	Relative humidity.
	P. ct.	*Min.*	*° C.*		*P. ct.*	*Min.*	*° C.*	
Ants (*Lasius niger* L., var. *americanus* Emery)	2.0	60	20	40	[1] 0.2	30	25	40
Aphids (*Myzus persicae* Sulz.)	1.0	60	25	40	.2	60	24	40
Bedbugs (*Cimex lectularius* L.)	.....	.....	.....	.....	2.0	30	27	40
Beetles, Colorado potato (*Leptinotarsa decemlineata* Say)	.....	.....	.....	.....	.5	15	30	40
Beetles, Flat grain (*Laemophlaeus minutus* Oliv.)	.5	60	24	40	1.0	60	26	40
Beetles, Potato flea (*Epitrix cucumeris* Harris)	1.0	60	20	40	.5	7	27	40
Beetles, Sawtooth grain (*Silvanus surinamensis* L.)	.5	60	25	40	1.0	30	28	40
Borers, Grain (*Rhizopertha dominica* Fab.)	.5	15	25	40	1.0	30	30	40
Flies[2]	.5	60	21	40	[3] .1	7	20	40
Fly larvæ[4]	1.0	30	25	40	.1	30	25	40
Fly, White (*Aleyrodes vaporariorum* Westw.)	.5	30	20	40	[3] .1	7	30	40
Mite, Phyllostachys bamboo (*Tarsonemus* sp.)	2.0	60	29	40	.2	60	24	40
Roaches (*Blattella germanica* L.)	1.0	60	25	40	.2	15	25	40
Roach (*Blattella germanica* L.) egg pods	3.0	60	25	40	.....	.....	.....	.....
Spiders, Red (*Tetranychus bimaculatus* Harvey)	[5] 3.0	120	29	40	.2	30	23	40
Weevils, Flour (*Tribolium ferrugineum* Fab.)	1.0	60	22	40	1.0	30	34	40
Weevils, Rice (*Calandra oryzae* L.)	.5	60	29	40	4.0	120	28	40

[1] *Lasius niger* L., var. *americanus* Emery and *Tetramorium caespitum* Fab.
[2] *Musca domestica* L.; *Stomoxys calcitrans* L.; *Chrysomyia macellaria* Fab.; *Lucilia sericata* Meig.; *Phormia regina* Meig.
[3] Not minimum lethal treatment. [4] *Muscina stabulans* Fall. [5] 99 per cent killed.

In most cases, longer exposure and higher concentrations were necessary in using arsine than in using hydrocyanic acid, two notable exceptions being grain borers and rice weevils. Arsine has many disadvantages as a fumigant, and can not be recommended for this purpose.

TABLE 4.— *Effect of arsine on seed germination.*

Kind of seed.	Germination.		
	Check.	2 per cent concentration (temp., 22 °C.; relative humidity, 40).	3 per cent concentration (temp., 22° C.; relative humidity, 40).
	Per cent.	*Per cent.*	*Per cent.*
Alfalfa, Dakota	79.5	81.0	76.0
Barley, Winter	82.5	80.5	85.5
Carrot, Oxheart	89.5	76.5	77.5
Corn, Miner's yellow dent	88.5	91.5	88.0
Field pea, Kaiser	91.5	82.5	84.0
Flax, Oregon	88.5	88.5	86.5
Lettuce, Black-seeded tennis ball	76.0	82.0	78.5
Muskmelon, Burnell's gem	79.0	76.0	78.0
Onion, Australian brown	24.5	23.5	31.0
Radish, Icicle	90.5	97.0	96.5
Rape, Winter	48.5	50.5	40.5
Rice, Mataribune	44.0	54.0	44.0
Soy bean, Mammoth yellow	18.0	24.5	4.5
Timothy	74.5	72.5	83.5
Wheat, Crimean	85.5	88.0	87.5

In some instances germination seems to have been stimulated, but for the most part the gas had no appreciable effect on the seeds.

Inasmuch as the check on soy beans was poor, the results in this case may be ignored.

Arsine does not prevent the growth of Fusarium, Ascochyta, or Colletotrichum exposed to it in concentrations up to and including 3 per cent for 60 minutes. It is of no value as a fungicide.

CYANOGEN CHLORID.

Cyanogen chlorid (CNCl), molecular weight 61.47, has a liquid density of 1.186 at 20° C. under its own pressure. Its boiling point is 15° C. The vapor pressure at 20° C. is 1,002 mm. of mercury. It is colorless, has an odor somewhat similar to that of hydrocyanic acid, and produces a violent lachrymosal effect. One volume of water dissolves 25 volumes of the gas. Cyanogen chlorid is less dangerous to human beings than hydrocyanic acid, because it can be detected when present in very low concentrations, while its presence in higher concentrations is unbearable because of its lachrymosal effect. Plant life is injuriously affected by cyanogen chlorid.

The concentration was determined in the same manner as was that of phosgene. Concentrations of from 0.1 to 4 per cent and exposures of from seven minutes to two hours were tried on insects. Fungi and seeds were exposed for longer periods.

The minimum lethal dose of cyanogen chlorid, as compared with that of hydrocyanic acid, is given in Table 5.

TABLE 5.— *Relative insecticidal action of cyanogen chlorid and hydrocyanic acid.*

Insects.	Cyanogen chlorid (100 per cent lethal).				Hydrocyanic acid (100 per cent lethal).			
	Concentration.	Time of exposure.	Temperature.	Relative humidity.	Concentration.	Time of exposure.	Temperature.	Relative humidity.
	P. ct.	*Min.*	*° C.*		*P. ct.*	*Min.*	*° C.*	
Ants (*Monomorium pharaonis* L.)	0.2	30	26	40	[1] 0.2	30	25	40
Aphids (*Myzus persicae* Sulz.)	.1	30	26	40	.2	60	24	40
Bedbugs (*Cimex lectularius* L.)	1.0	30	27	40	2.0	30	27	40
Bedbug (*Cimex lectularius* L.) eggs	1.0	60	28	40	.....	.....	.....	.....
Beetle, Colorado potato (*Leptinotarsa decemlineata* Say.)	.5	30	28	40	.5	15	30	40
Beetle, Colorado potato (*Leptinotarsa decemlineata* Say.) larvæ	.5	15	30	40	.5	15	30	40
Beetles, Flat grain (*Laemophlaeus minutus* Oliv.)	.5	120	31	40	1.0	60	26	40
Beetles, Potatoflea (*Epitrix cucumeris* Harris)	.5	15	27	40	.5	7	27	40
Beetles, Sawtooth grain (*Silvanus surinamensis* L.)	1.0	60	27	40	1.0	30	28	40
Borers, Grain (*Rhizopertha dominica* Fab.)	1.0	60	23	40	1.0	30	30	40
Flies[2]	.1	15	25	40	[3] .1	7	25	40
Fly larvæ	.5	15	24	40	.1	30	25	40
Fly, White (*Aleyrodes vaporariorum* Westw.)	.2	7	29	40	[3] .1	7	30	40
Mite, Phyllostachys bamboo (*Tarsonemus* sp.)	.2	30	29	40	.2	60	24	40
Roaches (*Blattella germanica* L.)	.5	30	25	40	.2	15	25	40
Roach (*Blattella germanica* L.) egg pods	2.0	60	23	40	.....	.....	.....	.....
Spiders, Red (*Tetranychus bimaculatus* Harvey)	.5	15	28	40	.2	30	23	40
Weevils, Flour (*Tribolium ferrugineum* Fab.)	2.0	60	24	40	1.0	30	34	40
Weevils, Rice (*Calandra oryzae* L.)	[4] 4.0	120	27	40	4.0	120	28	40

[1] *Tetramorium caespitum* Fab., and *Lasius niger* L., var. *americanus* Emery.
[2] *Musca domestica* L.
[3] Not minimum lethal treatment.
[4] 96 per cent killed.

The results in Table 5 show that the action of cyanogen chlorid as an insecticide is practically the same as that of hydrocyanic acid.

A preliminary series of germination tests run on several varieties of seeds showed that for the most part but little injury was done the seeds which were exposed to cyanogen chlorid for six hours at 1 per cent concentration, or for two hours at 3 per cent concentration. Exposure for more than six hours, however, affected injuriously the germination quality. Consequently, a longer series, with exposures not exceeding six hours, was run. The results thus obtained are reported in Table 6.

TABLE 6.— *Effect of cyanogen chlorid on seed germination.*

Kind of seed.	Germination.				
	Check.	1 per cent concentration.		3 per cent concentration, 1 hour (temp., 23° C.; relative humidity, 40; atmospheric pressure, normal).	1 per cent concentration, 1 hour (temp., 23° C.; relative humidity, 22; atmospheric pressure, vacuum).
		3 hours (temp., 23° C.; relative humidity, 40; atmospheric pressure, normal).	6 hours (temp., 23° C.; relative humidity, 40; atmospheric pressure, normal).		
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Barley, Himalaya	75.5	24.5	27.0	26.0	23.5
Barley, Kentucky winter	97.5	83.5	77.5	85.5	86.5
Barley, Manchuria	99.0	81.0	76.0	82.5	90.0
Barley, Moriart	99.5	92.0	91.5	96.0	97.0
Carrot, Danvers half long	77.5	78.5	72.5	75.0	74.5
Chenopodium ambrosoides	82.25	84.25	82.5	83.75	63.5
Clover, Alsiki	84.0	86.75	86.5	86.5	87.5
Clover, White	94.0	92.75	92.0	92.25	92.25
Clover, White sweet	83.5	82.5	77.5	80.5	73.5
Cucumber, Boston pickle	88.0	89.5	91.5	93.5	93.5
Flax, Salem, Oreg	85.5	86.5	85.0	85.5	86.0
Grass, Bermuda	92.5	88.0	84.5	88.0	85.0
Grass, Crested dog's tail	13.0	1.5	1.5	1.5	.5
Grass, Red top	86.0	80.0	89.75	85.0	85.5
Grass, Timothy	77.25	70.0	74.25	78.5	68.5
Kaoliang, Brown	96.0	21.5	20.5	27.0	25.0
Lettuce, Black-seeded Simpson	81.5	83.0	73.0	80.0	68.5
Lettuce, Grand Rapids	96.0	94.5	97.5	96.0	90.5
Lettuce, Salamander	67.5	72.0	78.5	73.5	72.0
Millet, Kursk	52.5	43.0	3.0	29.5	29.0
Milo, Dwarf	78.5	35.5	29.5	37.5	34.5
Muskmelon, Rocky Ford	76.0	66.0	76.5	75.5	71.0
Oats, Naked	91.0	69.0	59.5	67.0	61.5
Oats, Nebraska No. 21	95.5	78.0	86.0	86.5	90.5
Oats, Oregon winter turf	99.0	82.5	90.5	84.5	82.5
Oats, Swedish select	97.5	74.5	64.5	78.5	81.0
Parsley, Champion moss curled	81.5	79.5	78.0	81.0	77.5
Radish, Early scarlet turnip	97.5	92.5	92.0	95.5	96.5
Radish, Long scarlet short top	98.5	97.5	96.5	97.0	97.5
Radish, White icicle	90.5	84.0	85.5	87.5	90.0
Rice (grown in California)	94.0	90.0	89.5	92.5	85.0
Rice (grown in Louisiana)	94.5	97.0	92.5	97.0	83.5
Rice (grown in Porto Rico)	83.0	81.0	75.0	87.5	58.0
Salvia hispanica	36.5	21.5	20.5	18.5	16.5
Soy bean, Biloxi	90.0	59.0	88.0	89.0	95.0
Soy bean, Haberlandt	97.0	73.0	94.0	64.0	97.0
Teff	63.5	54.5	56.0	62.75	52.25
Trefoil, Yellow	38.5	31.5	33.0	26.0	33.5
Velvet bean, Alabama	96.0	81.0	85.0	65.0	89.0
Vetch, Hairy	85.5	84.5	92.5	84.0	86.5
Vicia villosa	97.5	99.5	99.0	98.5	96.0
Wheat, Arnontka	90.5	83.5	73.0	84.0	82.0
Wheat, Kharkoo	91.5	51.0	42.5	59.5	58.0
Wheat, Marquis	92.5	53.0	41.5	40.5	40.0
Wheat, White Australian	95.5	55.5	46.0	63.0	57.0

The germination of wheat, oats, and barley is lowered noticeably by treatment with cyanogen chlorid, and that of Salvia hispanica, kaoliang, velvet bean, milo, millet, and grass is injuriously affected.

Based on its action on Ascochyta, Colletotrichum, Fusarium, Penicillium, and Sclerotium, cyanogen chlorid shows possibilities of being an effective fungicide at a concentration of approximately 3 per cent, after an exposure of about 2 hours. The results of numerous experiments with fungi and bacteria on seeds indicate that this gas may be used against such organisms. Further work, however, is necessary to definitely determine this.

It having been shown that cyanogen chlorid is as poisonous to insects as hydrocyanic acid and also that it might prove useful as a fungicide for the treatment of stored products, some experiments were conducted to determine its effect on metals, paint, varnish and fabrics.

No effect was visible on the following metals, which, after having been cleaned and polished, were exposed to 1 per cent cyanogen chlorid for 24 hours in a fumigation box:

Aluminum.
Brass.
Copper.
Galvanized iron.
Iron.
Steel.
Tin.
Zinc.

Several paints and varnishes were exposed to a 1 per cent concentration of cyanogen chlorid for 24 hours in a fumigation box. In making these tests, a double coat of the paint or varnish was put on a 2-inch strip of pine and allowed to dry thoroughly. The treated strips were then fumigated, after which they were examined microscopically for change in finish, and also their color was compared with that of the corresponding unfumigated coating. No effect was visible in the case of the following:

American blue.
American vermilion.
Burnt sienna.
Burnt umber.
Chrome green, medium.
Chrome yellow, medium.
Drop black.
Inside varnish.
Lampblack.
Lead and oil.
Raw sienna.
Red lead.
Rose pink.
Valspar varnish.
Wall finish, white.
Yellow ocher.

CHLOROPICRIN.

Chloropicrin ($C(NO_2)Cl_3$), molecular weight 164.39, has a liquid density of 1.654 under its own pressure at 20° C. Its boiling point is 112° C. The vapor pressure at 20° C. is 18.9 mm. of mercury. It is colorless, very stable, and insoluble in water. It is said to explode on rapid heating, but no mention of any such accident is found in recent reports. Chloropicrin is a lachrymal and respiratory irritant.

Repeated exposure causes increased susceptibility, produces cough, nausea, and vomiting, and in large quantity may cause unconsciousness. Secondary effects are bronchitis, asthma, shortening of the breath, weak, irregular heart action, and gastritis. Liquid chloropicrin has a corrosive action on the skin, producing the effect of a severe burn without blistering. A wound thus made is slow to heal.

Because of the low vapor pressure of chloropicrin, it was necessary to force dry air through it, thereby bringing it to the saturation point, in order to obtain a concentration comparable with that of the gases already discussed. Although water is not soluble in chloropicrin, some moisture collects on the top of the liquid when humid air is passed through it, thereby causing variable humidity. The concentration at saturation is but 1.75 per cent at 20° C. The concentration was determined by absorption in a 2 per cent solution of sodium peroxid in 50 per cent alcohol. Titration by the method employed with phosgene and cyanogen chlorid was used.

Concentrations of from 0.5 to 1.75 per cent and exposures of from seven minutes to two hours were tried on insects.

The minimum lethal dose, with the minimum time, for chloropicrin, as compared with that of hydrocyanic acid, is given in Table 7.

TABLE 7.—*Relative insecticidal action of chloropicrin and hydrocyanic acid.*

Insects.	Chloropicrin (100 per cent lethal).				Hydrocyanic acid (100 per cent lethal).			
	Concentration.	Time of exposure.	Temperature.	Relative humidity.	Concentration.	Time of exposure.	Temperature.	Relative humidity.
	P. ct.	*Min.*	*° C.*		*P. ct.*	*Min.*	*° C.*	
Ants (*Monomorium pharaonis* L.)	[1] 0.5	7	20	40				
Ants (*Lasius niger* L., var. *americanus* Emery)					0.2	30	25	40
Ants (*Tetramorium caespitum* Fab.)					.2	30	25	40
Aphids (*Myzus persicae* Sulz.)	.5	30	21	40	.2	60	24	40
Bedbugs (*Cimex lectularius* L.)	1.0	30	23	40	2.0	30	27	40
Beetles, Colorado potato (*Leptinotarsa decemlineata* Say)					.5	15	30	40
Beetle, Colorado potato, larvæ					.5	15	30	40
Beetles, Flat grain (*Laemophlaeus minutus* Oliv.)	[1] .5	15	25	40	1.0	60	26	40
Beetles, Potato flea (*Epitrix cucumeris* Harris)	[2] .5	15	22	40	.5	7	27	40
Beetles, Sawtooth grain (*Silvanus surinamensis* L.)	1.0	30	27	40	1.0	30	28	40
Borers, Grain (*Rhizopertha dominica* Fab.)	1.0	30	27	40	1.0	30	30	40
Flies (*Musca domestica* L.)	[1] .5	7	26	40	[2] .1	7	25	40
Fly larvæ					.1	30	25	40
Fly, White (*Aleyrodes vaporariorum* Westw.)	[1] .5	7	21	40	[2] .1	7	30	40
Mite, Phyllostachys Bamboo (*Tarsonemus* sp.)	1.0	7	21	40	.2	60	24	40
Roaches (*Blattella germanica* L.)	.5	60	25	40	.2	15	25	40
Spiders, Red (*Tetranychus bimaculatus* Harvey)	.5	30	21	40	.2	30	23	40
Weevils, Flour (*Tribolium ferrugineum* Fab.)	1.0	60	27	40	1.0	30	34	40
Weevils, Rice (*Calandra oryzae* L.)	1.0	120	20	40	4.0	120	28	40

[1] Not minimum lethal dose.
[2] Impossible to obtain more insects to secure a definite low concentration and exposure.

The results reported in Table 7 show that chloropicrin is more toxic than hydrocyanic acid to some insects, especially toward the stored-product insects. The mites, however, appear to be more resistant to chloropicrin than to hydrocyanic acid.

To check the results obtained by Moore,[1] weevils, both flour and rice (*Tribolium ferrugineum* Fab., *Calandra oryzae* L.) and *Plodia interpunctella* Hbn. larvæ were fumigated with chloropicrin at the rate of 1 pound per 1,000 cubic feet. In the case of each insect, 50 individuals were placed in glass cylinders, which were then covered at both ends with gauze and put in the center of a 2-peck sack of oats where they were treated for 24 hours. On removal, all the insects were apparently dead, and none of them revived during a period of several days.

Germination tests, made on a number of varieties of seeds which had been fumigated with saturated chloropicrin gas for various periods, gave the result shown in Table 8.

TABLE 8.—*Effect of chloropicrin on seed germination.*

Kind of seed.	Germination.			
	Check.	1.75 per cent concentration (temperature, 20° C.; relative humidity, 0).		
		30 minutes.	60 minutes.	120 minutes.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Alfalfa, Common	49.0	42.0	35.0	41.0
Barley, Moriart	100.0	99.5	100.0	100.0
Carrot, Danvers half long	74.0	66.0	88.0	69.0
Corn, C. I. 119	99.5	100.0	99.5	100.0
Flax, F. H. B. 29057	94.0	94.5	91.5	93.5
Muskmelon, Burrell's gem	64.5	73.0	70.0	64.0
Onion, Australian brown	54.0	53.0	40.5	57.5
Radish, Scarlet globe	98.5	94.5	94.5	91.5
Rape, No. 1562	92.0	83.5	92.0	78.0
Rice, Honduras	89.5	95.5	96.0	96.0
Soy bean, Biloxi	75.0	85.0	76.5	81.5
Timothy, No. 29	66.0	81.0	92.5	86.0
Wheat, C. I. 180	97.0	95.5	97.0	97.0

Apparently chloropicrin stimulates the growth of rice and timothy and injures somewhat the seeds of alfalfa and radishes. The rest of the seeds showed no marked effects of the treatment.

The results of a series of experiments on Fusarium, Ascochyta, Penicillium, and Colletotrichum indicate that chloropicrin can not be used as a fungicide.

[1] Moore, Fumigation with chloropicrin. J. Econ. Entomol., 11 (1918): 357-362.

In order to determine the corrosive effect of the gas, several metals were cleaned and polished and then exposed to chloropicrin in a fumigation box, with the following results:

Concentration of gas	0.25 per cent.	1 per cent.
Time of exposure	24 hours.	2 hours.
Temperature	21° C.	26° C.
Relative humidity	30.	30.
Metal.	Action.	Action.
Brass	No visible effect	Very slight corrosion.
Steel	do	Do.
Aluminum	do	No visible effect.
Iron	do	Do.
Galvanized iron	Very slight corrosion	Do.
Tin	No visible effect	Do.
Copper	Very slight corrosion	Do.
Zinc	do	Do.

Double coats of a number of paints and varnishes were applied to 2-inch strips of pine and allowed to dry thoroughly, after which they were exposed to chloropicrin in the same manner as the metals. After fumigation, they were examined with a microscope to detect any change in finish, and their color was compared with that of an untreated sample. When exposed for 24 hours, at a temperature of 21° C. and a relative humidity of 30, to a gas of 0.25 per cent concentration, or for 2 hours at a temperature of 26° C. and a relative humidity of 30, to a gas of 1 per cent concentration, no effect was visible in the case of the following materials:

American blue.
American vermilion.
Burnt sienna.
Burnt umber.
Chrome green medium.
Drop black.
Lampblack.
Lead in oil.
Raw sienna.
Red lead.
Rose pink.
Valspar varnish.
Wall finish white.
Yellow ocher.

The action of chloropicrin on fabrics has been determined by Moore.[1]

Several varieties of cloth of different colors were exposed to 1 per cent cyanogen chlorid for 24 hours in a fumigation box. The effect on the color was noted, as well as any other injury done. No tensile strength tests were made, but the samples were tested by pulling the treated and the untreated fabrics and comparing the results. The color was not visibly affected, nor could any injury be detected in the following fabrics after treatment:

Satin, fancy (malachite green).
Peau de cygne (tobacco brown).
Pongee (natural color).
Surah (gray and white shepherd's plaid).
Poplin, silk and wool (white).
Satin, cotton back (midnight blue).
Flannel (white).
Velours (dark brown).
Poplin, all-wool (black).
Homespun (brown and white).
Organdie (rose pink, pale green, light blue, and orange).
Sateen (royal purple, lemon yellow, cardinal red).
Voile (flesh pink and lavender).
Gingham (dull gray blue).
Gingham, chambray (green)
Linen, sage green.
Linen, imitation (Alice blue, pink, and coral).

[1] Loc. cit.

ILLUMINATING GAS.

The results of a series of experiments with illuminating gas on the same varieties of insects as were employed in the tests previously discussed, using a concentration of 3 per cent and an exposure for two hours, showed that it is not toxic to insects. Consequently no detailed data are given.

CARBON MONOXID.

Carbon monoxid also proved to be nontoxic to insects at a concentration of 3 per cent and an exposure for two hours. The same varieties of insects were used as in the preceding tests.

SUMMARY.

The results of the action on insects of all the gases tested, with the exception of illuminating gas and carbon monoxid, are given in Table 9.

CONCLUSIONS.

Phosgene is not useful as an insecticide, because of its toxicity toward human beings, its high vapor pressure, the difficulty of controlling it, and its comparatively low toxicity toward insects. Neither does it possess any value as a fungicide.

Arsine has no advantage other than ease of generation, and possesses many disadvantages as an insecticide. Its toxicity toward insects is comparatively low, it is injurious to plants, and has no effect on fungi.

Illuminating gas in concentrations up to 3 per cent and for exposures up to two hours is not toxic to insects.

Carbon monoxid in concentrations up to 3 per cent and for exposures of two hours is not toxic to insects.

Of the gases tested, cyanogen chlorid and chloropicrin give promise of being useful for fumigation purposes. Neither of these, however, can be used in greenhouse fumigation, because of their injurious action on plants. Nevertheless they probably can be used in the fumigation of stored products.

The efficiency of chloropicrin as an insecticide is undoubted. In general, it is more poisonous to stored-product insects than hydrocyanic acid. Other advantages which it possesses are ease of handling and control, low toxicity toward human beings, ease of detection, and noninflammability. Its disadvantages are its adherent quality, which makes it necessary to air the material for some time after it has been fumigated, its corrosive action on metals, its severe lachrymal effect, and its low volatility. The last objection may be partially overcome by pouring the dose required on paper, thereby increasing the evaporating surface.

TABLE 9.—*Effect of some toxic gases on insects.*

Insects.	Phosgene (100 per cent lethal).				Arsine (100 per cent lethal).				Cyanogen chlorid (100 per cent lethal).				Chloropicrin (100 per cent lethal).				Hydrocyanic acid (100 per cent lethal).			
	Concentration.	Time of exposure.	Temperature.	Relative humidity.	Concentration.	Time of exposure.	Temperature.	Relative humidity.	Concentration.	Time of exposure.	Temperature.	Relative humidity.	Concentration.	Time of exposure.	Temperature.	Relative humidity.	Concentration.	Time of exposure.	Temperature.	Relative humidity.
Ants (*Monomorium minimum* Buckley)	*Per ct.* 0.5	*Min.* 30	°*C.* 19	19	*Per ct.*	*Min.*	°*C.*	.....	*Per ct.*	*Min.*	°*C.*	.....	*Per ct.*	*Min.*	°*C.*	.....	*Per ct.*	*Min.*	°*C.*	.....
Ants (*Tetramorium caespitum* Fab.)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.2	30	25	40
Ants (*Lasius niger* L., var. *americanus* Emery)	.....	.....	.....	.....	2.0	60	20	40	.....	.....	.....	.....	.....	.....	.....	.....	.2	30	25	40
Ants (*Monomorium pharaonis* L.)	.....	.....	.....	.....	.....	.....	.....	.....	0.2	30	26	40	[1] 0.5	7	20	40	.....	.....	.....	.....
Aphids (*Myzus persicae* Sulz.)	1.0	30	31	40	1.0	60	25	40	.1	30	26	40	.5	30	21	40	.2	60	24	40
Bedbugs (*Cimex lectularius* L.)	2.0	120	26	40	.....	.....	.....	.....	1.0	30	27	40	1.0	30	23	40	2.0	30	27	40
Bedbug eggs	2.0	120	24	40	.....	.....	.....	.....	1.0	60	28	40	.....	.....	.....	.....	.....	.....	.....	.....
Beetles, Colorado potato (*Leptinotarsa decemlineata* Say)	4.0	120	30	40	.....	.....	.....	.....	.5	30	28	40	.....	.....	.....	.....	.5	15	30	40
Beetle, Colorado potato, larvæ	4.0	120	30	40	.....	.....	.....	.....	.5	15	30	40	.....	.....	.....	.....	.5	15	30	40
Beetles, Flat grain (*Laemophlaeus minutus* Oliv.)	1.0	120	29	40	.5	60	24	40	.5	120	31	40	[1] .5	15	25	40	1.0	60	26	40
Beetles, Potato flea (*Epitrix cucumeris* Harris)	1.0	60	30	40	1.0	60	20	40	.5	15	27	40	[2] .5	15	22	40	.5	7	27	40
Beetles, Sawtooth grain (*Silvanus surinamensis* L.)	1.0	120	28	40	.5	60	25	40	1.0	60	27	40	1.0	30	27	40	1.0	30	28	40
Borers, Grain (*Rhizopertha dominica* Fab.)	2.0	60	29	40	.5	15	25	40	1.0	60	23	40	1.0	30	27	40	1.0	30	30	40
Flies [3]	[4] .5	7	26	40	[5] .5	60	21	40	[6] .1	15	25	40	[6] .5	7	26	40	[1] .1	7	25	40
Fly larvæ [7]	[8] 3.0	120	26	40	[7] 1.0	30	25	40	[6] .5	15	24	40	.....	.....	.....	.....	.1	30	25	40
Fly, White (*Aleyrodes vaporariorum* Westw.)	[1] 1.0	30	22	40	.5	30	20	40	.2	7	29	40	[1] .5	7	21	40	[1] .1	7	30	40
Lice, Body (*Pediculus corporis* De G.) eggs	[9] 3.0	120	23	40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mite, Phyllostachys bamboo (*Tarsonemus* sp.)	1.5	30	25	40	2.0	60	29	40	.2	30	29	40	1.0	7	21	40	.2	60	24	40
Roaches (*Blattella germanica* L.)	1.5	120	27	40	1.0	60	25	40	.5	30	25	40	.5	60	25	40	.2	15	25	40
Roach egg pods	3.0	120	30	40	3.0	60	25	40	2.0	60	23	40	.....	.....	.....	.....	.....	.....	.....	.....

Spiders, Red (*Tetranychus bimaculatus* Harvey)	.5	60	31	40	[10] 3.0	120	29	40	.5	15	28	40	.5	30	21	40	.2	30	23	40
Weevils, Flour (*Tribolium ferrugineum* Fab.)	[11] 4.0	120	23	40	1.0	60	22	40	2.0	60	24	40	1.0	60	27	40	1.0	30	34	40
Weevils, Rice (*Calandra oryzae* L.)	[8] 4.0	120	26	40	.5	60	29	40	[12] 4.0	120	27	40	1.0	120	20	40	4.0	120	28	40

[1] Not minimum lethal treatment.
[2] Supply of insects exhausted.
[3] *Musca domestica* L.; *Calliphora vomitoria* L.; *Muscina stabulans* Fall.
[4] Equal to or less than but not more than.
[5] *Musca domestica* L.; *Stomoxys calcitrans* L.; *Chrysomyia macellaria* Fab.; *Lucilia sericata* Meig.; *Phormia regina* Meig.
[6] *Musca domestica* L.
[7] *Muscina stabulans* Fall.
[8] 90 per cent killed.
[9] 90.6 per cent killed.
[10] 99 per cent killed.
[11] 86 per cent killed.
[12] 96 per cent killed.

As an insecticide, the effect of cyanogen chlorid is practically the same as that of hydrocyanic acid. Its disadvantages are its injurious effect on plant life, low boiling point, slightly corrosive action on metals, and severe lachrymosal effect. Its advantages are that it is active as a fumigant, is easily detected, is not injurious to seeds in doses which are toxic to insects and fungi, and is no more toxic toward human beings than hydrocyanic acid. It is safer to use than hydrocyanic acid, because it can be detected in lower concentrations.

More experiments on the fungicidal aspect are necessary to work out in greater detail the methods of its use. Since it is a dry gas and does not injure the seeds, its use would offer a decided advantage over the present method of treatment for fungi, whereby the seeds are moistened, which sometimes causes germination before it is desired.

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